FIRST-YEAR RESULTS OF THE ONGOING PALEONTOLOGICAL INVENTORY OF PETRIFIED FOREST NATIONAL PARK, ARIZONA

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Petrified Forest National Park (PEFO) in northeastern Arizona contains some of the premier exposures of Late Triassic terrestrial sediments in the world. The majority of these sediments are fluvial in origin, belonging to the Petrified Forest Member of the Chinle Formation, and are Late Carnian through Early-Middle? Norian in age. The park is renowned for its fabulous preservation of numerous fossil logs, but park sediments also preserve diverse vertebrate and invertebrate faunas, along with abundant plant and trace fossil records, providing an excellent template for the Late Triassic ecosystem.

The first paleontological work in the PEFO area consisted of preliminary studies of fossil trees, beginning with the Whipple Expedition of 1853, which produced the first description of the petrified wood deposits (Figures 1 and 2). Almost 50 years later, a paleobotanist with the U.S. Geological Survey, Lester Ward, performed a reconnaissance of the area. Ward recognized both the significance of the deposits and the dangers facing them and recommended their preservation (Ash 1972b). On December 8, 1906, President Theodore Roosevelt created the Petrified Forest National Monument to protect these unique paleontological resources for future study.

Although the legendary John Muir collected vertebrate fossils from the "forests" in the early twentieth century, Charles L. Camp (Figure 3) of the University of California at Berkeley (UCMP) was the first to conduct extensive collection and documentation of vertebrates in the area of the park, starting in 1921 and continuing for almost a decade (Long and Murry 1995). This work culminated with an extensive monograph on the phytosaurs published in 1930 in which Camp stressed the biostratigraphic utility of vertebrate fossils in Late Triassic sediments of the American Southwest. Camp (1930) was the first to document distinct vertebrate faunal zones in the Chinle Formation, which influenced the modern biostratigraphic systems of Long and Ballew (1985) and Lucas (1998). Spurred by Camp's success, Edwin H. Colbert of the American Museum of Natural History and Charles W. Gilmore of the U.S. National Museum conducted fieldwork in the 1930s and 40s. Unfortunately other projects, most notably Colbert's discovery of the Ghost Ranch Quarry in 1947, ultimately kept both parties from doing more extensive work in the park, but small yet significant collections were made by each institution. Colbert was also very interested in the erosional rates of the Chinle Formation because on several noted occasions he had uncovered vertebrate fossils completely destroyed by summer rainstorms (Colbert 1946). In 1951 he placed a series of sharpened wooden stakes in the mudstones of the Tepees area and returned periodically to monitor the amounts of erosion (Colbert 1956, 1966).

During the next few decades paleontological work in the park was conducted mainly by park naturalists, with research concentrating heavily on paleobotany. This emphasis was spurred by the discovery of the first leaf fossils from the area in 1932 during construction of the present park

Figure 1. Amiel W. Whipple, Lieutenant, U.S. Army Corps of Topographical Engineers. Whipple provided the first description of petrified wood deposits (Black Forest) in current park boundaries. He gave the name Lithodendron Wash to the major drainage running through the Painted Desert portion of the park. (U.S. Signal Corps Photo No. 111-B6326 in the National Archives, reproduced from Ash 1972b)

road. Park naturalists Myrl V. Walker and later Howard R. Stagner conducted much of the preliminary work, with the majority of the descriptions being done by Lyman Daugherty (Figure 4) of San Jose State College in California, who produced a dissertation on the Triassic plants of Petrified Forest in 1941 (Daugherty 1941). Daugherty remained active in paleobotanical studies in the park over the next few decades, publishing and describing several new species (Daugherty 1960). Since the 1960s, Sidney Ash of Weber State University (now retired from academia) has continued to research the plants of the Chinle Formation, resulting in numerous publications and many new interpretations for the Triassic ecosystem (Ash 1972a, 1989, 2001; Ash and Creber 2000).

From 1978 to 1979 the Museum of Northern Arizona (MNA) conducted a paleontological site inventory of the vertebrates in conjunction with the creation of a base geo-

Figure 2. Sketch of the Lithodendron Wash area from Whipple (1855). Possibly the first published depiction of Triassic plant fossils in the American Southwest. (Reproduced from Ash 1972b)

logical map of the park (Cifelli et al. 1979). This inventory resulted in the collection of numerous vertebrate fossils and the documentation of more than 70 new sites. In 1981, a field team from UC Berkeley led by Robert A. Long came to the park to reinitiate the biostratigraphic work started by Camp 60 years earlier. Armed with Camp's old photos and field notes, the group quickly relocated most of the old UCMP sites and discovered a significant amount of new sites and material (Long and Padian 1986). The initial season was such a success that Long spent the next six summers in the park documenting more than 100 new vertebrate localities and collecting thousands of specimens, quadrupling the known faunal diversity in the park (Long and Murry 1995). In later years Long concentrated his research on invertebrate and plant localities as well (Long, field notes). In recent years Hunt (1998), Hunt and Wright (1999), and Heckert (2002) have conducted studies of vertebrate macro and microfossils in the park in hopes of learning more about the origin of the dinosaurs in the Late Triassic.

Bryant (1965) conducted a brief and unsuccessful reconnaissance of fossil invertebrates as part of a larger study of the Chinle ecosystem by the University of Arizona. More recently, Good (1993) has documented the molluscan fauna of the Chinle Formation, including numerous sites from PEFO.

Ichnofossil research, influenced by studies by Walker (1938) and Caster (1944), has been reinitiated in the last decade with vertebrate tracks, invertebrate traces, and insect nests being the main focus (Hasiotis and Dubiel 1995; Santucci et al. 1998; Hasiotis et al. 1998). In addition, work has been done on pollen and amber (Litwin et al. 1992) and insect predation on leaves (Ash

Figure 3. Charles Lewis Camp. At the invitation of Miss Annie Alexander, benefactor of the UCMP, Camp arrived in the Petrified Forest area in 1921 and continued work in the area through 1930, resulting in the first publication of Petrified Forest vertebrates. (Photo courtesy of UCMP)

1999, 2000). As a result of all of this combined research there are currently more than 400 documented historical paleontological localities at PEFO.

In May of 2001 a project was initiated to attempt to relocate as many of the known paleontological sites as possible, documenting them with photography and global positioning technology. The goal is to create a working database for resource management purposes, namely inventory and monitoring of fossil resources, as well as to create a useful platform for future researchers with locality data for all known paleontological localities being compiled and stored in both paper and digital mediums. Acquired data are to be used to place localities and fossils in a biostratigraphic framework and to establish protocol for periodic site monitoring. Finally, all collected information is to be used in the development of a paleontological resource management plan for the park.

PREVIOUS PALEONTOLOGICAL INVENTORIES

MNA's 1978 through 1979 survey terminated with the creation of a locality map and an accompanying report (Cifelli et al. 1979). This map and report included the historical localities of Camp, Colbert, and the early park naturalists as well as more than 80 new localities mapped from throughout the park. Unfortunately it is not clear whether the historical localities were physically relocated

Figure 4. Lyman H. Daugherty, San Jose State College. Daugherty was the first to produce a comprehensive study of the flora of the Petrified Forest. (PEFO photo collections)

in the field or simply plotted from an older existing map, although the latter seems most likely based on recent field observations. Additionally, the newer localities were roughly mapped on a 1:50,000 topographic map and accompanied by very brief descriptions, making relocation of these sites extremely difficult if not impossible.

In 1989, a set of locality sheets from the park was compiled for most of the known vertebrate localities, especially those discovered by UCMP during the 1980s. The numbering and nomenclature system developed for these data sheets is replicated in the Triassic monograph of Long and Murry (1995); this work was accompanied by a set of locality photographs taken by Long in 1990. Unfortunately, the computer program that generated the locality sheets contained an error, which deleted site information from many of the forms, and only a third of the 178 documented sites possessed accompanying photographs.

In 1993 workers from the University of Arizona assembled a GPS map of paleontological localities for use as an erosional prediction model and cyclic monitoring tool (Guertin and Kunzmann 1993), and in 1994 Evanoff undertook a compilation of all known site data and generated a master map of all known vertebrate localities with an accompanying report correlating many of the various site numbers used by different institutions (Evanoff 1994). Sadly the 1993 map and accompanying data are missing and cannot be found. In addition, the 1994 map was also done at the 1:50,000 scale and none of the localities were field checked for accuracy. A more extensive correlation of vertebrate locality names and numbers can be found in Parker (2002).

METHODS

Preliminary research was conducted to obtain as much historical site location data as possible. This was a daunting task that is still continuing. The small amount of information available at PEFO was widely scattered, and missing information needed to be collected from outside repositories.

Gathered information included field notes, maps, and photographs. When this information allowed precise relocation of historical sites, the information was updated. New information collected includes GPS coordinates and photos, as well as lithologic and stratigraphic data. Updated photo documentation not only verifies relocation of a site but also aids in the monitoring process, as a series of time lapse photos can show erosional changes and ground disturbances in the area (Figure 5). Thorough notes of each site were completed and will be retained at PEFO. Coordinates for each site were recorded with a Trimble Explorer hand-held receiver using the NAD 1927 datum and then downloaded into Trimble's Pathfinder Office Software. Whenever possible the datapoints were differentially corrected through the Prescott U.S. Forest Service office. These data were then used to construct a GIS locality map using ArcView 3.2.

RESULTS

Because most of the available locality information dealt with the vertebrate localities, these were the main focus for the first year. As of September of 2002, more than 80 (35%) of the 225 known vertebrate sites had been relocated and documented. An additional 35 new vertebrate sites have been documented as well. The inventory has also resulted in the collection of several important specimens including excellent specimens of phytosaurs, the aetosaur *Stagonolepis wellesi*, and a spenosuchian cf. *Parrishia mccreai*.

Additionally, the existing locality sheets have been updated and greatly expanded to include considerable amounts of information regarding each site. The present database will allow future researchers to quickly and accurately relocate specific paleontological sites and all of the information pertinent to these sites.

DISCUSSION—PROBLEMS IN RELOCATING SITES

The primary limitations hindering the relocation of historical paleontological sites are the lack of physical indicators, missing field notes, no photo documentation, and imprecise mapping of sites. Physical indicators of past quarrying sites can include rock and soil disturbance, bone fragments, and plaster, burlap, and other refuse left from excavation efforts. Erosion rates in the Chinle can be as high as 6 mm per year (Colbert 1966), erasing many of the physical signs of fossil collection. Furthermore, at many sites, specimens were surface collected with no resulting ground disturbance.

Most of the past researchers in the park kept notes of their work. Unfortunately until very recently many of these field notes were not available. Recovery of missing researcher notes is ongoing although, admittedly in many cases, they do not contain enough information for exact site relocation. Field and report maps do exist but in most cases the localities have been imprecisely mapped, sometimes with an error as large as three quarters of a mile.

The best tool for site relocation has been photography. With a rough map coordinate and a good photograph almost any locality can be relocated. Unfortunately many of the sites were not photo documented, especially those of the MNA and the early park naturalists. Future researchers will be required by the park to accurately document all new sites, especially regarding photo documentation.

TO COLLECT OR NOT TO COLLECT?

One of the questions often raised by park managers is what is the best way to preserve and protect the fossil resources in our national parks. The inclination of many NPS managers is to not allow fossil collection within the park units, assuming this is the best way to protect the fossil resources. Regarding specific types of fossil resources this may be true but in the case of the vertebrate fossil resources at PEFO, noncollection is not the best way to preserve and protect. For example, the fossil logs of PEFO, consisting chiefly of silica, are highly resistant to weathering and erosion. Recent photographic evidence shows that the logs break down significantly slower than the surrounding mudstone matrix. We compared recent

Figure 5. An example of reshoot photography from the inventory project. In 1923 Charles L. Camp hired two local men with horses and scraper to remove overburden at the Crocodile Hill Quarry. Top: 1923 photo of the work (courtesy of UCMP). Bottom: Same site in 2002 (PEFO photo collections).

photos of the Long Logs area with photos taken in the 1890s, which depict the exact same logs practically unchanged, whereas mudstone buttes in the background show the disappearance of several feet of rock. In this case, collection of these specimens for protection is not necessary and would in fact harm the deposit. The same is true for sandstone blocks containing ichnofossils. Although slightly more erosive than the fossil logs, trackways generally will survive weathering processes for long periods of time. The leaf fossils of PEFO occur in distinct siltstone horizons and are therefore protected by burial, not needing collection as a protective measure.

The vertebrate fossils, however, are easily destroyed by the erosive forces of wind and water. Most of the vertebrate fossils at PEFO occur in bentonitic mudstones and shales. These clays absorb rainwater, swelling to several times their original volume. Upon drying the swelling clays are reduced to powder and any fossil bones contained in these layers are reduced to fragments. Fortunately the weathering horizon is only a few inches deep so any bone existing below that level is not destroyed, but as the weathering surface itself is in a constant state of erosion, mudstone layers that contain vertebrate material are continuously being exposed and the fossils destroyed. Colbert (1966) showed that the erosion of the fossiliferous mudstone layers in the park measures about 6 mm per year, or close to a meter each century! Although this does not appear to affect the fossil wood resources adversely, numerous vertebrate fossils are destroyed each year. Colbert (1946) documented the loss of several bone elements after a single summer rainstorm. Figure 6 shows the lower jaw of a phytosaur that has been exposed for several years and thus destroyed. Obviously leaving exposed bones

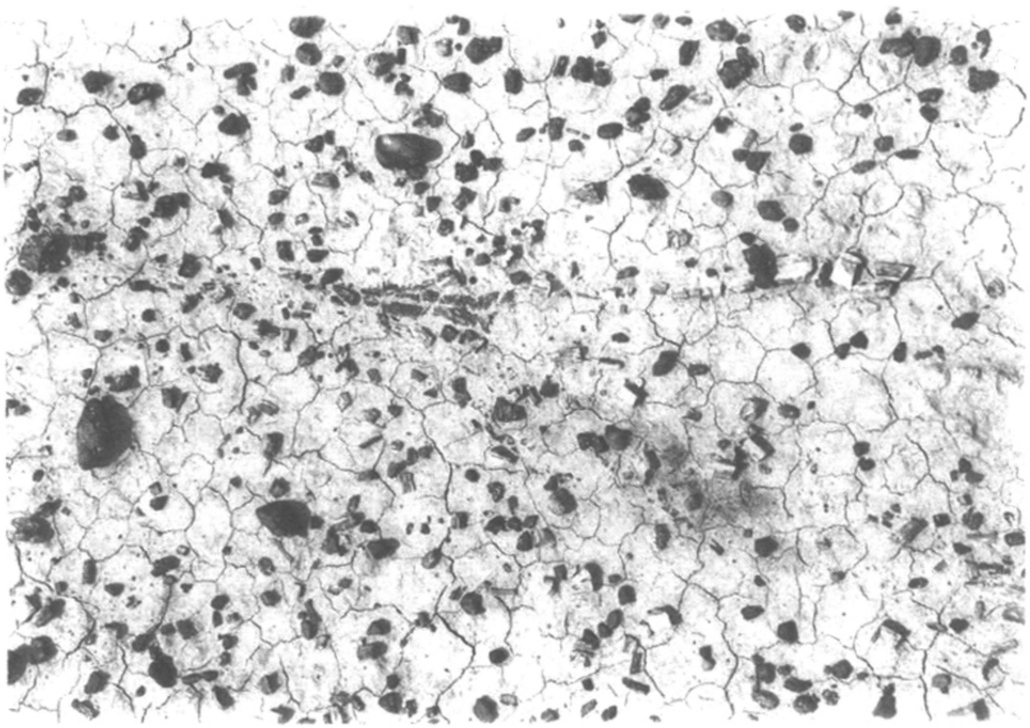

Figure 6. A phytosaur lower jaw destroyed by exposure and subsequent erosion. (PEFO photo collections)

in the field only leads to their destruction, and to a loss of scientific information. We therefore believe that the best protection for vertebrate fossils is their collection, consolidation, and curation to allow future study. Preservation of the resource is better effected by creation of a periodic monitoring program for known fossil sites and the collection of important, endangered specimens.

FUTURE WORK

This inventory is an ongoing project that will take several years to complete. Future goals include relocation and documentation of the plant, ichnofossil, and invertebrate sites, establishment of a cyclic monitoring program for known sites, and the implementation of a paleontological resource management plan for the park.

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